BIODIVERSITAS
Volume 18, Number 3, July 2017
Pages: 1179-1189

ISSN: 1412-033X
E-ISSN: 2085-4722
DOI: 10.13057/biodiv/d180341

Bycatch of sharks, marine mammals and seabirds in Indonesian Tuna Longline Fishery

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Manuscript received: 11 May 2016. Revision accepted: 20 July 2017.

Abstract. *Zainudin IM, Patria MP, Rahardjo P, Yasman, Gautama DA, Prawira WT. 2017. Bycatch of sharks, marine mammals and seabirds in Indonesian Tuna Longline Fishery. Biodiversitas 18: 1179-1189.* Bycatch in longline fishery is recorded to be one of the major factors defining the declined populations of endangered marine species worldwide. This research aimed to identify bycatch level of sharks, marine mammals and seabirds as well as to pinpoint the mitigation options in Indonesian tuna longline fishery. In this study, a total of 8,564,858 hooks were observed from 5,622 gear settings in Indonesian tuna longline fishery based in two major fishing ports, namely Bitung Fishing Port-North Sulawesi and Benoa Port-Bali from May 2006 to June 2014. The results suggest that the best hook rate per thousand hooks in Indonesian tuna longline fisheries for shark bycatch was 0.2446, followed by 0.0030 for seabird bycatch, 0.0021 for dolphin bycatch and 0.0009 for whale bycatch. Seabirds largely acquired in the dead condition while the other species were found still alive (sharks and marine mammals). Bycatch of seabirds only occured in the vessels based in Benoa Bali, and the correlation value (R^2) of sharks and seabirds caught at night time was low while for marine mammals was very strong. Deep setting system of fishing gears and night setting also proved to be more effective to reduce bycatch of those critical marine species.

Keywords: bycatch, hook rate, Indonesia, tuna longline, mitigation effort

INTRODUCTION

Bycatch can always be found in every fishing activity and becomes one of the largest and most extensive threats to the marine environment (WWF 2004). Of those bycatch threats, many parties has a main concern to the marine species, especially those that have critical roles in the ecosystem and also have a long life cycle such as seabirds, marine mammals, elasmobranchs (e.g. sharks and rays) and sea turtles. When the mortality level of those species is high, their population is endangered because the sustainable condition of their life cycle is very vulnerable (Lewison et al. 2004; Heppel et al. 2005 in Read 2007; Stobutzki 2006).

The mortality rate of sharks caused by incidental catch (bycatch) is considerably high, so the shark population is in dangerous condition (Camhi et al. 1998; Mandelman et al. 2008). In addition, around 50 million sharks die every year because of bycatch using unregulated fishing gears such as longline, gillnet and trawl. Offshore swordfish fisheries in Taiwan, Japan and Spain regularly catch sharks in large number using bycatch which then practices shark finning (IUCN-SSC 2001). Nineteen shark species are exploited using bycatch in 17 Canadian waters which most of them using longline as one of types of fishing gears (Joyce 1999). Meanwhile, in Indonesia, majority of shark fishery products are mostly using bycatch (72%), and only 28% using a specific catching tools to get the main target (Zainudin 2011).

In the case of seabirds, longline is believed to be the main factor causing the failure of conservation efforts for various types of seabirds (Anderson et al. 2011). Recently, many global initiatives had been campaigned to reduce the bycatch level of seabirds in longline fishery. This also becomes the main concern of many NGOs, government institutions and international or regional organizations (Brothers et al. 1999). The population of 40 seabird species especially from albatross and petrel family decreased almost 50% because of sheer level of bycatch (Brothers et al. 1999; Cooper et al. 2001). Around 14,000 seabirds were incidentally captured in longline fishery, Alaska from 1993 to 1997. The annual bycatch rate was reported around 0.090 seabirds per 1,000 hooks in Bering Sea/Alutian Islands-BSAI (Stehn 2001). Jimenez and Domingo (2009) also reported that the world highest bycatch level of seabirds was found in Uruguayan pelagic longline fishery operating in Atlantic region. The average bycatch level was 0.42 seabird per one thousand hooks (from 1998-2004). Furthermore, it was stated that the bycatch rate interval varied with the peak season started from May to November with 2.50 seabirds per 1,000 hooks, and during the lean season it would be achieved around 0.04 seabirds per 1,000 hooks. It is globally estimated that around 160,000 seabirds perish every year. It is predicted that those number will increase to more than 320,000 seabirds because of incidental catch activities in global longline fisheries (Anderson et al. 2011).

Besides the bycatch issues of sharks, seabirds and sea turtles, the bycatch issues of dolphin as one of biggest cetacean groups in the spot of tuna fishery, now, becomes a high concern issue worldwide (Cullet et al. 1996). In addition, the interactions between fisheries and cetaceans in the longline fishery have drawn attention from many parties in terms of socio-economic and ecological aspects (Gilman et al. 2006). Of these reasons, bycatch could still be the biggest threat to the sustainability of world's cetacean population (Reeves 2005; Read et al. 2006). For example, Forney and Kobayashi (2007) reported that from 1994 to 2005, 67 cetaceans has been incidentally captured from 24,542 number of observed gear settings in Hawaii longline fishery where 7 of them died and 60 cetaceans were injured due to they were getting hooked or entangled. In the southwest of Indian Ocean, cetacean bycatch in longline fishery for targeting tuna and swordfish was then limited to the oceanic species, especially pilot whale (Kizka et al. 2009). In addition, Gilman et al. (2006) stated that the interactions with fisheries could lead to behavior change of cetaceans in terms of forage for food and distribution patterns.

The objectives of the study were to analyze characteristic interactions between bycatch of marine species including sharks, marine mammals, and seabirds; and tuna longline gears operated in Indonesian waters, and also to evaluate and recommend better mitigation options of shark, marine mammal and seabird bycatch in Indonesian tuna longline fishery. Characteristic interactions between marine species and tuna longline gear will be focused on bycatch hotspots, hook rates, marine species which were incidentally captured and other factors that also contribute to the increased level of marine species bycatch in tuna longline fishery.

MATERIALS AND METHODS

The research was conducted in the tuna longline fleets operating in territorial and Exclusive Economic Zone (EEZ) waters-Indonesia, which were focused in two main fishing ports Benoa, Bali and Bitung, North Sulawesi, Indonesia. Tuna longline fleets located in Benoa-Bali were chosen as sample of fishing vessels operating in Indian Ocean and Indonesian archipelagic waters (Banda, Flores and Maluku), and the vessels based in Bitung-North Sulawesi had fishing ground, which was spread all over Pacific Ocean. The map of research locations could be seen in Figure 1.

The data of this study was collected from May 2006 to June 2014 as part of the continuation of WWF monitoring activities and onboard observation program in Indonesia tuna longline fishery. Primary data was collected directly by independent onboard observers at tuna longline fleets located in Benoa Port-Bali and Bitung Port-North Sulawesi. The independent observers performed direct observation onboard during fishing trips. They also collected data that comprised many parameters such as boat and gear specification, the depth of gear setting, bait used, setting and hauling location, each bycatch species and its measurements, hook positions, conditions of the species while being captured and after release, capture time, and so forth.

Figure 1. Map of research locations in Benoa, Bali (red circle) and Bitung, North Sulawesi (yellow circle), Indonesia (two main ports where tuna fishing vessels observed were based)

The intensity of shark, marine mammals and seabird bycatch was analyzed using the hook rate calculation by following the equation adapted from formulation proposed by Nasution (1993), based on catched fish in every 100 hook traps that had been adjusted into every 1,000 hook traps for bycatch species. Since the research object was bycatch species and the equation was actually created to calculate target species; therefore, for this analysis the target species was replaced by bycatch species (sharks, marine mammals and seabirds). The analysis would be focused only on hook rates of bycatch species by excluding detached hooks or escaped-bycatch species from the fishing gear.

The equation is:

$$HR = \frac{nf}{N} \times 1000$$

Where:
HR : hook rate of bycatch species per 1,000 hooks
nf : number of hooks with bycatch species attached to them
N : number of overall deployed hooks

The catched species, especially sharks as one of seven species having the highest commercial value (for the fin) and the most utilized ones, were mainly observed. Some of those shark species were also protected by national and regional regulations. The seven shark species included blue shark (*Prionace glauca*), leafscale gulper shark/dogfish (*Centrophorus squamosus*), shortfin mako shark (*Isurus oxyrinchus*), tiger shark (*Galeocerdo Cuvier*), great hammerhead shark (*Sphyrna mokarran*), silky shark (*Carcharhinus falciformis*), and pelagic thresher shark (*Alopias pelagicus*). Due to limitations of available information, the species of seabirds, dolphins, and whales could not be identified, yet.

ArcGIS 10 was used to identify bycatch hotspots and to detect potential bycatch hotspots in tuna longline fishery. An analysis of the correlation coefficient (R^2) performed by using Microsoft Excel program to determine the correlation between the number and time of bycatch species being captured became the main focus of the study. The interpretation of the correlation coefficient used a categorization formula according Sugiyono (2006) that classified the relationship of correlation coefficient into five categories as follows: very low (R^2 = 0.00 to 0.199), low (R^2 = 0.20 to 0.399), moderate (R^2 = 0, 40-.599), strong (R^2 = 0.60 to 0.799) and very strong (R^2 = 0.80 to 1.000).

Data collected by onboard observers as well as analysis results would provide comprehensive description of patterns and conditions of shark, marine mammal and seabird bycatch in Indonesia including the other information such as the intensity, hook rate, time, depth, and type of bait which is relevant to the increase of bycatch level, bycatch hotspots, and survival rate in the future.

To develop recommendations and action strategies as options to find the best mitigation of bycatch sharks, marine mammals and seabirds in tuna longline fishery, information and research results as well as relevant literatures were classified in this study to offer solutions. The classifications were then analyzed by using simple statistical comparisons for quantitative information, and scrutinized further for the scientific rationale for the qualitative information. The best decision to mitigate bycatch in longline tuna fishery was concluded by comparing the results of this study with the conditions of eligibility and compliance of Indonesian tuna longline fishery.

RESULTS AND DISCUSSION

Results

In this study, a total of 8,564,858 hooks were observed from 5,622 gear settings in Indonesian tuna longline fisheries (71 fishing vessels) located in two major ports, i.e Bitung Port in North Sulawesi and Benoa Port in Bali from May 2006 to June 2014 (Table 1). A total of 41 tuna longline vessels based in Benoa Port, Bali and 30 vessels based in Bitung Port, North Sulawesi involved in the study by conducting 203 fishing trips (1 trip lasted in 1-3 months). The bait mostly used was sardines, and fishers also sometimes used scads and squids as bait. For particular periods (during full moon), fishers also used live bait of milkfish. The main target species of Indonesia tuna longliners included yellowfin tuna (*Thunnus albacares*), bigeye tuna (*Thunnus obesus*), southern bluefin tuna (*Thunnus maccoyii*) and albacore (*Thunnus alalunga*).

Based on Figure 2, most of observed tuna longline vessels were operated in international waters (> 200 nautical miles) besides in territorial waters and EEZ of Indonesia. Particularly vessels based in Port Benoa-Bali were mostly operated in international waters in the Indian Ocean region. Therefore, they were subject to the rules of the RFMOs-Regional Fisheries Management Organizations such as IOTC (Indian Ocean Tuna Commission), WCPFC (Western and Central Pacific Fisheries Commission) and CCSBT (Commission for the Conservation of Southern Bluefin tuna). All of these RFMOs had a policy for the management and ecological conservation related to species such as sea turtles, sharks, seabirds and marine mammals.

During the study, 26 sea birds, 18 dolphins, 8 whales and 2,095 sharks were caught accidentally in tuna longline gears (Figure 4A and Figure 5A). See Figure 3 for the bycatch hotspots. Hook rate per thousand hooks in Indonesian tuna longline fisheries for whale bycatch was 0.0009, followed by 0.0021 for dolphin bycatch, 0.0030 for seabird bycatch and 0.2446 for shark bycatch (Figure 4b and Figure 6). The number of seabird, dolphin and whale bycatch in Indonesian tuna longline fishery was lower than that in the United States, in line with the bycatch level of sharks that could also be considered lower than the average of global shark bycatch hook.

From the 7 shark species, the most species that incidentally captured in Indonesian longline tuna fishery was blue shark (643 sharks, with hook rate 0.0751), followed by silky shark (545 sharks, with hook rate 0.0636), thresher shark (101 sharks, with hook rate 0.0118), gulper shark (54 sharks, with hook rate 0.0063), hammerhead shark (25 sharks, with hook rate 0.0029), mako shark (10 sharks with hook rate 0.012) and then tiger shark (7 sharks, with hook rate 0.0008).

Results also showed that tuna longline fleets located in Bitung Port had higher level of bycatch whales and sharks (hook rate for whale: 0.0011; and for sharks: 0.4793) compared to those in Benoa Port (hook rate for whales: 0.0009; and for sharks: 0.1782) (Figure 4b and 6). This happened because of the different setting system of Tuna longline fleets located in Bitung Port and in Benoa Port. In Bitung Port, the setting system of hooks was deployed at the shallow water column (approximately <100 m). On the other hand, Tuna longline fleets based in Benoa Port used deep setting system by deploying hooks at the deep-water column (at the depths of 200-300 m). However, the bycatch level of another marine species such as seabirds and dolphins at tuna longliners based in Benoa Port was higher if compared to those in Bitung Port.

Table 1. Vessel number, vessel weight, number of trip and duration, number of gear setting, number of hooks and deep setting of hook observed during the study (period covered 2006-2014).

Information	Unit	Amount (based on the fishing port)		Total amount
		Benoa	Bitung	
Vessel number	vessel	41	30	71
Vessel weight	< 10 GT	0	0	0
	10-30 GT	27	13	40
	31-30 GT	4	6	10
	> 50 GT	12	11	23
Number of fishing trip	Trip	130	73	203
Duration of fishing trip	< 1 Month	64	33	97
	1-3 Month	54	35	89
	> 3 Month	12	5	17
Setting number of fishing gear	Times	4.173	1,449	5,622
Number of hook	Hooks	6,676,677	1,888,181	8,564,858
Deep setting of hook	Meter	200-350	50-100	-

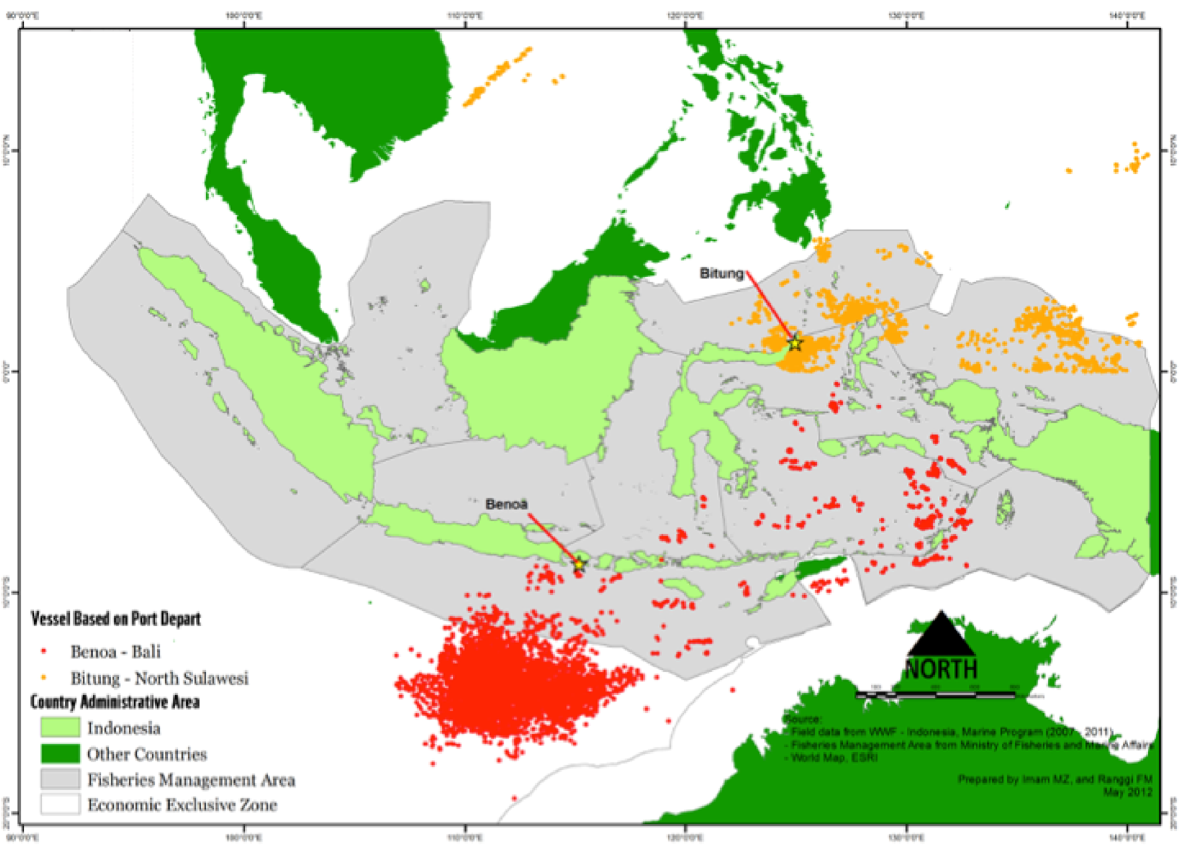

Figure 2. Gear setting and hauling locations of Indonesian tuna longliners observed (period covered 2006-2014)

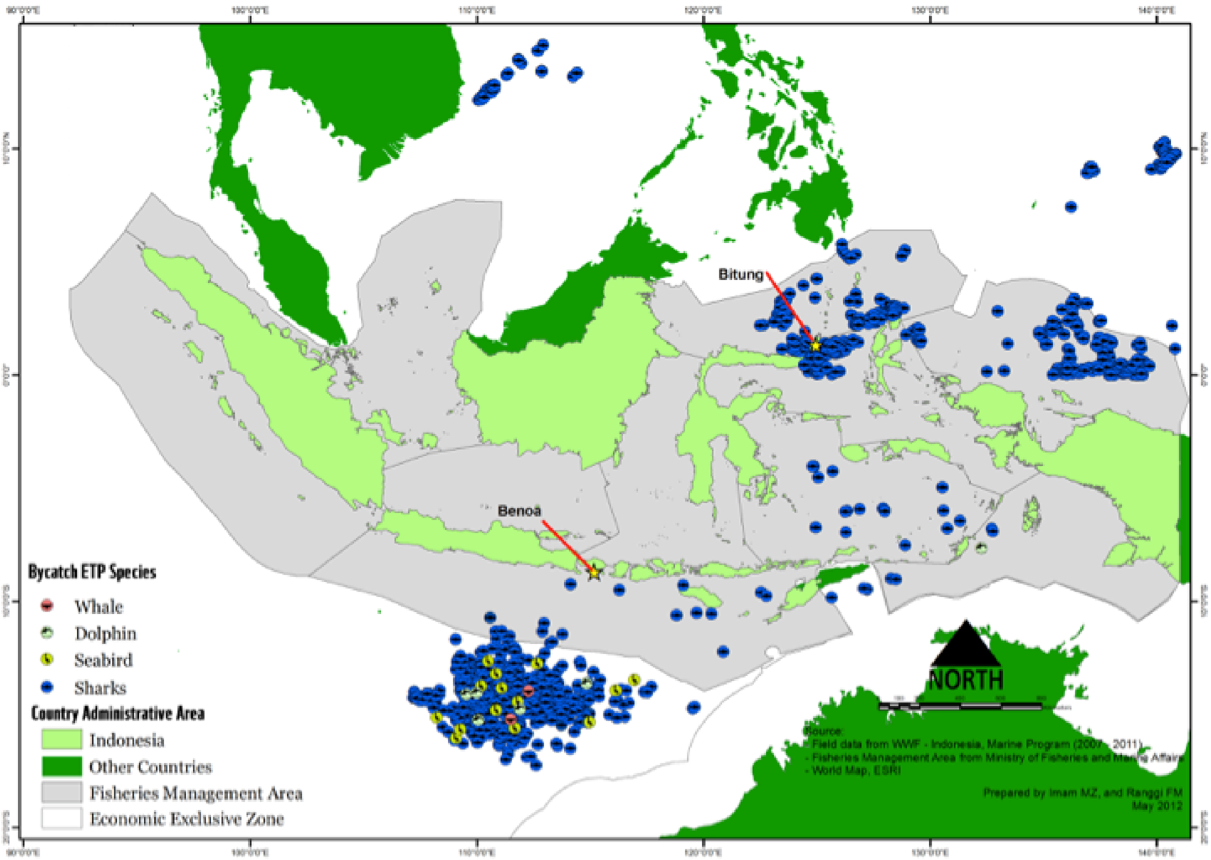

Figure 3. Bycatch hotspots for sharks, seabirds, dolphins and whales in tuna longline fishery (period covered 2006-2014)

The sex ratio of sharks caught between female and male was 1: 0.91. Table 2 shows that 52.42% of captured sharks were females and the rest of 47.58% was males. Another caught-shark species, known as hammerhead shark, was mostly females (75%). The maturity rate of a shark bycatch obtained by measuring total fork length showed that 98.19% of captured sharks were juveniles and sub-adults, and only 1.81% of them were adult (Table 2).

Figure 7 shows that most of the sharks (73.3%) were trapped by hook in the mouth, and only few of them were stuck in the digestive system/swallowed (15 %), and the rest were attached outside of the body part or entangled. In terms of survival rate, sharks trapped by hook in their digestive system, inside their mouth, and entangled were mostly alive condition when they were captured, but sharks trapped by hook outside of their body parts were commonly dead (Table 3). Fins of all sharks were removed, so the observation of post released-condition could not be performed.

Table 2. Percentage of sex and maturity shark bycatch in tuna longline fishery (period covered 2006-2014)

Species	Sex				Maturity			
	Female		Male		Adult		Juvenile	
	Individual	Percentage (%)	Individual	Percentage (%)	Individual	Percentage (%)	Individual	Percentage (%)
Blue shark	277	51.30	263	48.70	11	1.71	632	98.29
Leafscale gulper shark	17	53.13	15	46.88	1	1.85	53	98.15
Shortfin mako shark	4	50.00	4	50.00	1	10.00	9	90.00
Tiger shark	4	57.14	3	42.86	0	0.00	7	100.00
Hammerhead shark	18	75.00	6	25.00	3	12.00	22	88.00
Silky shark	224	47.86	244	52.14	5	0.92	539	99.08
Thresher shark	53	57.61	39	42.39	4	3.96	97	96.04
Other species	357	55.01	292	44.99	0	0.00	0	0.00
Total identified shark	**954**	**52.42**	**866**	**47.58**	**25**	**1.81**	**1359**	**98.19**

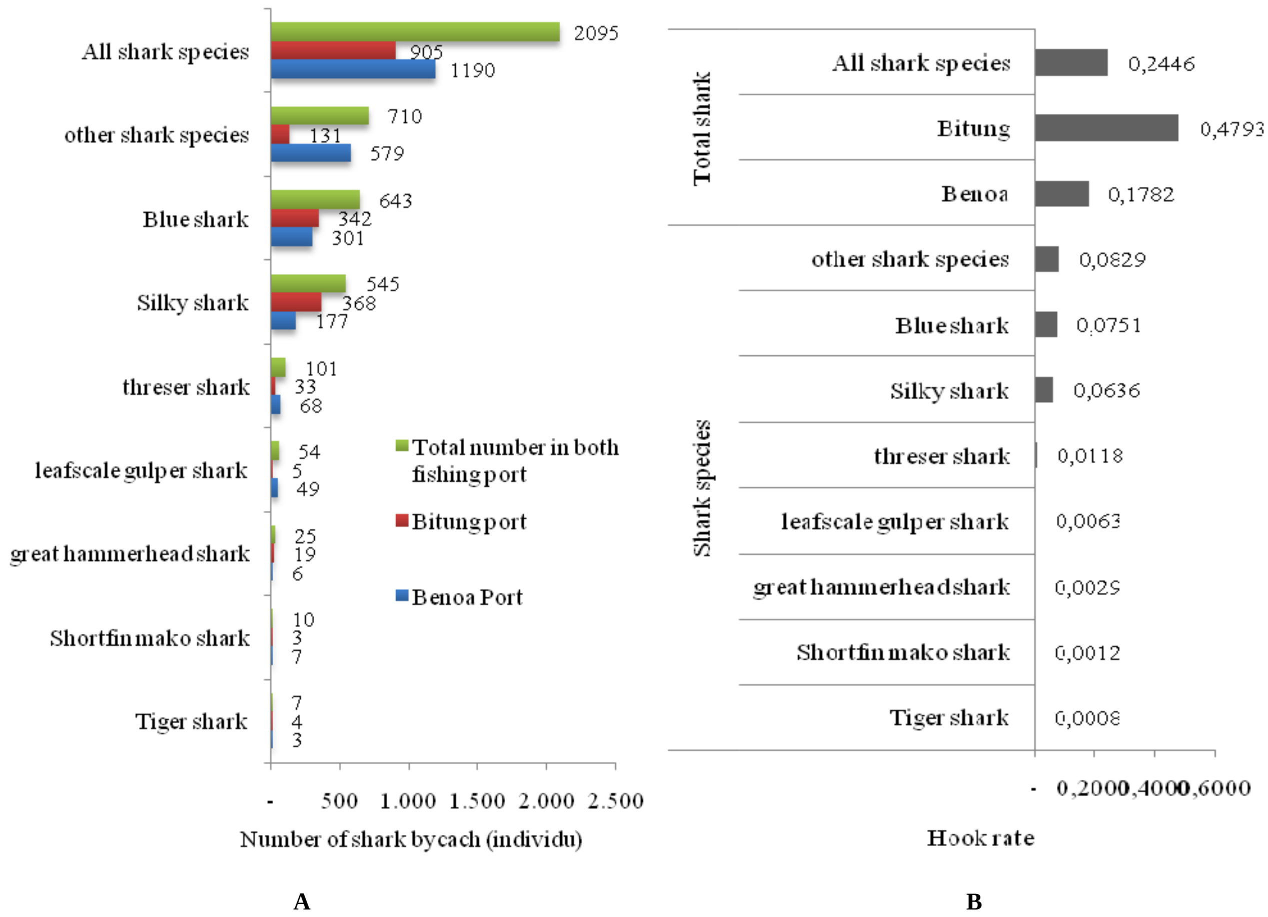

Figure 4. Bycatch level and hookrate of sharks at tuna longline fishing vessels based in Benoa and Bitung Port from 2006-2014. A. Number of observed shark bycach at tuna longline fishery (2006-2012), B. Hook rate of observed shark bycach at tuna longline fishery (2006-2012)

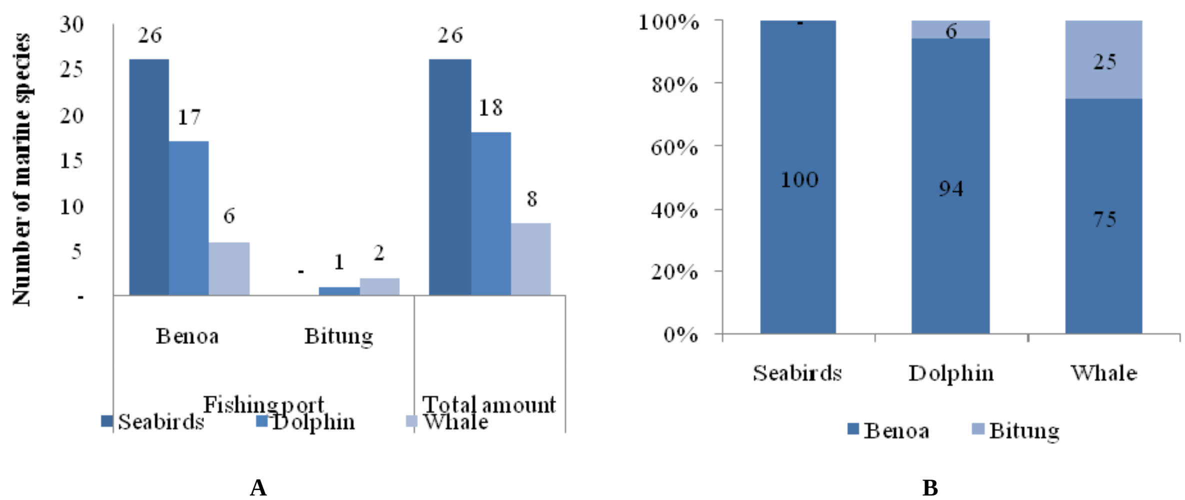

Figure 5. Level and percentage of seabird, dolphin, and whale bycatch at tuna longline fleets based in Benoa and Bitung Port from 2006-2014. A. The bycach number, B. The bycach percentage

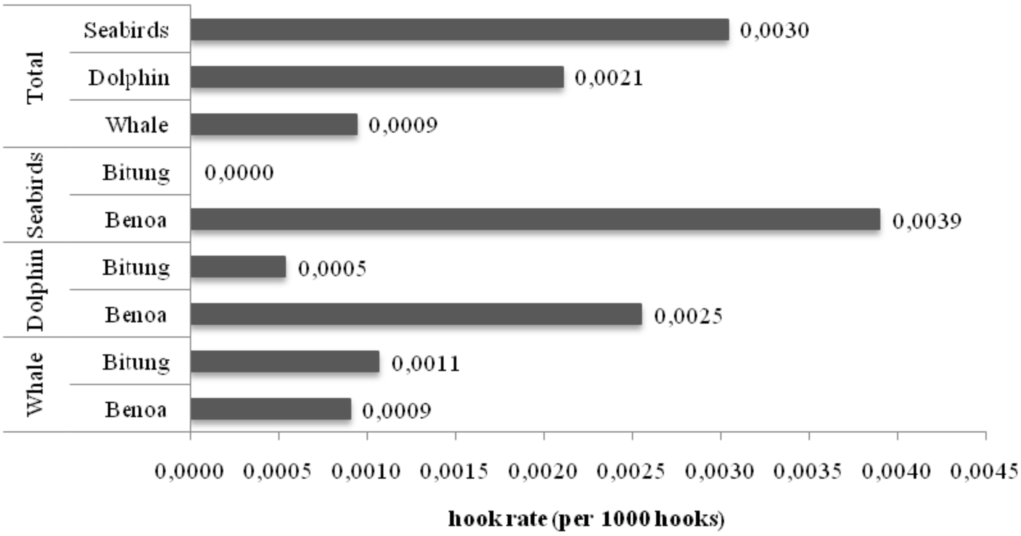

Figure 6. Hook rate of seabird, dolphin and whale bycatch in tuna longline fishery (period covered: 2006-2014)

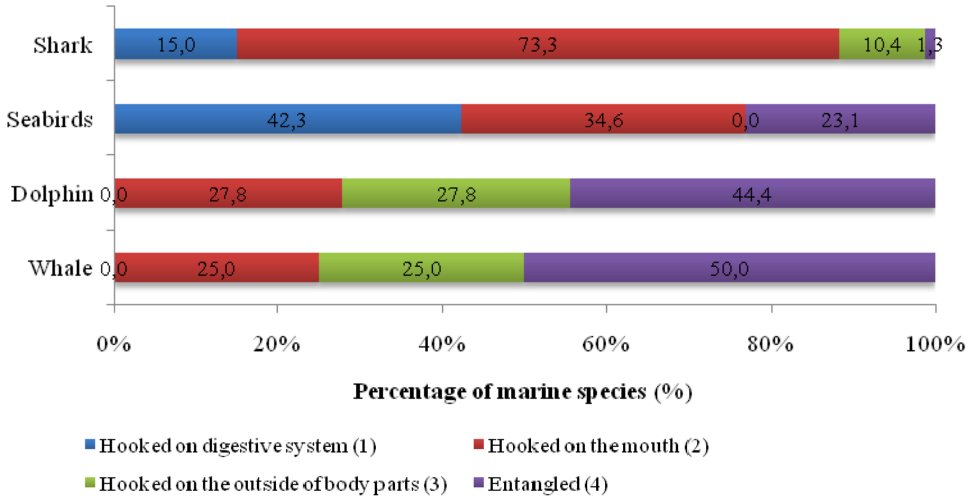

Figure 7. Percentage of hook positions for shark, seabird, dolphin and whale bycatch at tuna longline vessels based in Benoa and Bitung Port (period covered 2006-2014)

For seabird bycatch, 42.3% of seabirds were hooked in their digestive system, 34.8 % of them were trapped in the mouth, and 23.1 % of them were entangled (Figure 7). Most of the seabirds bycatch were dead because of hook trap (73%), especially when they got hooked in digestive system (81.8%) and mouth (88.9%). However, if they were still alive, all of them could be released back safely to the wild. All of the entangled seabirds (66.7%) were alive and released back safely to the wild (Table 4).

Dolphins (72.2%) and whales (75%) were also mostly entangled in the outside of body parts, and the rest were hooked on the mouth (whale: 25.0% and dolphins: 27.8%). Most of them were still alive and released back safely to the sea. For dolphins, all of them were alive while getting caught and released back safely to the sea (100%). All whales (100%) were alive (either getting hooked in the mouth or outside body parts) and released back safely to the sea. However, most of the entangled whales (75%) were found dead (Table 4).

Table 4. Survival rate percentage of seabird, dolphin, and whale in relation to hook position during capture and release back to the sea (period covered 2006-2014)

Hook position and total number of marine species	Condition of marine species	Seabirds (%)		Dolphin (%)		Whale (%)	
		Live	Dead	Live	Dead	Live	Dead
Hooked on the digestive system	Captured	18.2	81.8	0	0	0	0
	Released *)	0	100	0	0	0	0
Hooked on the mouth	Captured	11.1	88.9	100	0	100	0
	Released *)	100	0	100	0	100	0
Hooked on the outside of the body part	Captured	0	0	60	40	100	0
	Released *)	0	0	100	0	100	0
Entangled	Captured	66.7	33.3	75	25	25	75
	Released *)	100	0	100	0	50	50
Total number of marine species	Captured	26.9	73.1	77.8	22.2	62.5	37.5
	Released *)	71.4	28.6	100	0	83.3	16.7

Note: *) it is percentage of marine species condition when captured still alive only

Table 3. Number and percentage of shark bycatch survival rate in relation to hook positions (period covered 2006-2014)

Hook Position	Live		Dead	
	Indi-vidual	Percent-age (%)	Indi-vidual	Percent-age (%)
Hooked on digestive system	248	78.73	67	21.27
Hooked on the mouth	1266	82.42	270	17.58
Hooked on the outside of the body part	101	46.54	116	53.46
Entangled	15	55.56	12	44.44
Total shark	1630	77.80	465	22.20

Table 5. Correlation between night fishing and the increase of bycatch level of whales, dolphins, seabirds and sharks (period covered: 2006-2014)

Marine species	R^2	Interpretation*
Seabirds	0.30769	Low
Sharks	0.34961	Low
Whales	0.80000	Very strong
Dolphin	0.88235	Very strong

Note: R^2: Correlation value, * : interpretation of correlation value based on sugiyono (2006)

Table 5 indicates that the relationship between the intensity of bycatch level at night time was low (R^2 = 0.3491 for sharks and R^2 = 0.30769 for seabirds). Moreover, the relationship between the intensity of whale and dolphin bycatch level with night fishing was very strong (R^2 = 0.88235 for whales and R^2 = 0.80000 for dolphins).

Discussion

Shark, marine mammals and seabird bycatch number and species in Indonesia compared to other countries

Based on hook rate of marine species bycatch including seabird (0.0030), dolphin (0.0021) and whale (0.0009) in Indonesian tuna longline fishery, bycatch level in Indonesia was lower than that in America. This was also seen in shark bycatch (0.2446) that tended to be lower than the average of global hook rate. The hook rate of shark bycatch from various fisheries ranged from 0.7 to 17 per 1,000 hooks (Gilman et al. 2007). It is estimated that hook rate average of shark bycatch in Pacific Ocean longline fishery was 16.47, while Atlantic Ocean was 21.17 and the Indian Ocean was 4.33 (Kettemer 2012). Indonesia is one of the world largest shark producers (Lack and Sant 2006), and most of the shark products are generated form bycatch (72 %), where only 28 % of sharks were captured as the main target species (Zainudin 2011). Furthermore Zainudin (2011) stated that gillnet and longline are the types of gears that greatly contribute to the sheer shark bycatch level compared to any other gear types.

In 2000, the number of seabird bycatch (albatross) in Hawaii longline fishery reached up to around 2,300 albatrosses; however, after the application of side-setting recommended by experts, the number of seabird bycatch in longline fishery plummeted to only 100 seabirds in 2016 with hook rate ranging from 0.002 to 0.01 per 1.000 hooks (Rivera 2008). Regarding to cetacean bycatch, it was estimated that from 1999 to 2003, 132 pilot whales and 45 risos dolphins were dead due to they were incidentally captured or badly injured in longline fishery in the east coast of the United States (Waring et al. 2006). Pilot whales (*Globicephala spp.*) and Risso's dolphins (*Grampus griseus*) are the main species which mostly had the interaction with longline gear (Garrison 2007).

Of the seven shark species identified in this study (Figure 4), blue shark was the most shark species captured fleets in Indonesian tuna longline. This study was similar to Bromhead et al. (2012) who found that blue shark is the main bycatch species captured in tuna longline fishery in Mashall Island. This species was captured during night fishing, cold weather and full moon period where thermocline layer was closer to the surface waters (shallow mixed layer) and during El Nino conditions. Research in west Mediterranean Sea especially in swordfish longline also found that the main bycatch species is blue shark, followed by mako shark (De La Serna et al. 2002). In

Indonesian fisheries, there were five species of sharks that mostly being caught include blue shark (*Prionace glauga*), hammerhead sharks (*Spyrna lewini*), whitetip reef shark (*Triaenodon obesus*), grey reef shark (*Carchahinus amblyrhynchos*) and pelagic thresher shark (*Alopias pelagicus*) (Zainuddin 2011).

Sex ratio and maturity rate of shark bycatch

Based on data of sex ratio, most of sharks captured in Indonesian longline fishery were females; with the ratio of female to male was 1: 0.91. The sex ratio, which is not very far apart, indicates the healthy population of either female or male sharks. This result was consistent to other study conducted by De la Serna et al. (2002) who reported that the sex ratio of female and male of shark bycatch in swordfish longline fleets in the western Mediterranean Sea was 1:0.9. However, 95.7% of the sharks caught in Indonesian tuna longline fishery were juveniles and sub-adults. The high pressure of juvenile shark population could disrupt the recovery process of whole shark population in the sea because the bycatch hotspots of captured juveniles sharks may be the nursery ground of shark. Therefore, the management of fishing operation must be regulated to ensure the sustainability of shark population. Marine bycatch mostly had a negative impact to the caught marine species which could be clearly seen from the increase of mortality rate of shark juveniles (Hall et al. 2000).

Factors contributing to the increase of shark, marine mammal and seabird bycatch level on tuna longliners: the depth of gear setting and gear setting time

Tuna longline fleets located in Bitung Port using shallow setting system had higher bycatch hook rate of whales and sharks compared to those in Benoa Port which used deep setting system (Figure 4b and 6). Several studies on the vertical pattern of shark movement suggest that oceanic Whitetip shark and silky shark are vulnerable to shallow setting gears, while blue sharks usually dive into the deep water during daytime and come to the surface at night. This makes blue sharks vulnerable to both shallow and deep setting systems. On the other hand, thresher sharks dive into shallow water during daytime. They are also very active at dusk, but they rarely come to the surface, thus thresher sharks are extremely susceptible to get captured by tuna longliners which use deep setting system (Boggs 1992; Nakano et al. 2003; Weng and Block 2004; Bonfil et al. 2008; Musyl et al. 2011). Shallow setting in tuna longline fishery generally resulted in higher shark bycatch level compared to deep setting system (Gillman et al. 2007). Deep setting system, which mostly without the installation of branch lines at the depth less than 100 m has contributed to the reduction of shark and turtle bycatch numbers (Beverly et al. 2007).

The number of seabird and dolphin bycatch was higher at tuna longline fleets based in Benoa Port compared to those in Bitung Port. Although all cetaceans have to come to the surface to breathe, some whales can dive deeper and stay in the water longer than other cetaceans. Dolphins often stay near water surface for around 15 to 20 minutes. Sperm whales can dive deeper up to 1,000 meters or more. After diving in, the whales recover their energy by resting near water surface (National Aquarium 2016). The behaviors of whales and dolphins make them to be vulnerable for being caught on longline gear. Whales are susceptible to get captured on both deep and shallow setting systems, while dolphins are more susceptible to get caught on shallow setting.

In the case of sea birds, albatrosses and petrels along with other sea birds, they are interacting with fisheries when they are searching for food. They eat fish species used as bait or discarded by fisheries (Anderson et al. 2011). The interaction between seabirds foraging pattern with the fishing fleets leads to the increase of mortality rate of seabirds due to bycatch, either by getting hooked or entangled (Brothers 1991).

Based on Table 5 indicates that the relationship between the intensity of bycatch level at nighttime was low. Moreover, the relationship between the intensity of whale and dolphin bycatch level with night fishing is very strong. Based on those conditions, the reduction of soaking time during night fishing or performing night fishing could reduce bycatch of cetaceans (whales and dolphins). While the mitigation options for sharks would be greatly varied depending on the shark species. Night fishing will block visual capabilities of seabirds in chasing fish bait. This is also recommended by many parties to avoid the capture of seabirds in longline fishery (Brothers 1991; Gilman 2006). The catch average and vertical habitat of sharks also depend on the effects of daytime or night fishing (Gilman et al. 2008). In general, fishermen believe that the setting depth, bait and soaking time can contribute to the total shark catch rate (Gilman et al. 2007).

Correlation between hook positions and survival rate of shark, marine mammal and seabird bycatch

From the four hook positions, the most recurring conditions were as follows: sharks get hooked on the mouth, seabirds get hooked on the digestive organ, and most of the dolphins as well as whales get entangled or hooked on the outside body part (Figure 7). Survival rate percentage of each marine species could be concluded as follows: 77.8% of sharks were alive, 73% of seabirds were dead, 77.8% dolphins were alive and 62.5% of whales were alive (Table 3 and Table 4).

The hook position while marine species get captures can determine their survival rate of the marine species (Ryder et al. 2006; Parga 2012). Hook position attached to the body parts of shark bycatch is associated with severe injury (Godin et al. 2012). Godin et al. (2012) further explained that sharks getting hooked on the mouth might get less severe injuries compared to those who are getting hooked on the internal organ (deep hooking). This is also associated with the low level of shark mortality onboard or after release.

From all the marine species observed in this study (Table 4), most of the seabirds were found dead after being incidentally captured. Most of the time when the longline is set before deployment, seabirds are hooked or entangled since they eat the bait and finally get dragged and drown along with the gear (Gilman 2006). Therefore, the bycatch of seabirds are mostly found dead.

For marine mammals, about 50% of a pilot whales caught on pelagic longline gear were entangled on mainline and the rest were hooked on the mouth (Garrison 2008). Garrison (2008) further explained that fishers would try to release back the entangled (not hooked) sea mammals back to the sea. However when they are hooked, for instance on the mouth, fishers would cut the line to release the mammals back to the sea and leave hooks being attached on the mouth.

Mitigation options for shark, marine mammal and seabird bycatch in longline fishery

Some mitigation options for shark, marine mammal and seabird bycatch in pelagic longline fishery was reviewed from other studies conducted by Gilman 2006; Beverly et al. 2007; Gilman et al 2007; Clark et al. 2014 as follows: in the case of seabirds, the mitigation options were classified into three categories: (i) avoiding fishing activities in areas that had high risk of interaction with seabirds for example in open and closure and night setting, (ii) blocking access to the bait for example using sinker, fishing line launcher, gear setting from the side of the vessel, bird repellents strings/streamer line), and (iii) changing the bait for example using artificial bait and bait coloring.

For marine mammals (including cetaceans), the studies are still limited. However one of the mitigation options that could be offered was to change the hook material into the less strong one (weak hook) in order to release large-sized marine species (whales and dolphins) but the hook was still strong enough to smaller sized fish as the main target of the fishery such as tuna and billfish.

Hook rate of shark was mostly determined by type of bait usage, soaking time, hook shape, line length and material, the depth of gear setting, and supporting devices specifically used to target sharks. On the other hand, survival rate of hooked or entangled shark during hauling and handling is quite varied, depending on shark species, size, area and fishing practices as well as vessel navigation. Some approaches recommended to reduce shark bycatch in longline fishery included by reducing soaking time, deep settings and changing fishing ground when the location is identified as shark bycatch hotspot.

From this study, it can be concluded that deep setting system and night setting have been proven to be more effective in reducing bycatch of sharks, seabirds, and marine mammals. The characteristics of shark, marine mammals and seabird bycatch in Indonesian tuna longline fishery in term of hook rate of whale bycatch, dolphin, seabird and shark bycatch was lower than average global bycatch hook rate. Based on the location of observed bycatch, it could be seen that tuna longline fleets based in Bitung Port using shallow setting system had lower bycatch level of seabirds and dolphins compared to those in Benoa Port using deep system setting. On the contrary, tuna longliners based in Bitung Port had higher bycatch level of whales and sharks (including Great hammerhead shark). Of the seven shark species identified in the study, blue shark was the most species that frequently captured in Indonesian longline tuna fishery incidentally. All the sharks captured were mostly juveniles or sub-adults. Most of the sharks, dolphins and whales were captured in alive condition except for seabirds that generally were found dead after being incidentally captured.

ACKNOWLEDGEMENTS

This research was financially supported by WWF-Indonesia fisheries program. The authors are grateful and thanks to onboard observers as frontliner for onboard data collection in each fishing trips of tuna longline vessels.

REFERENCES

Anderson ORJ, Small CJ, Croxall JP, Dunn EK, Sullivan BJ, Yates O, Black A. 2011. Global seabird bycatch in longline fisheries. Endang Spec Res 14: 91-106.

Beverly S, Curran D, Musyl M. 2007. Deep setting longline to avoid bycatch. Proceeding of Forth International Fisheres Forum. Western Pacific Regional Fishery Management Council, Puntarenas.

Boggs C. 1992. Depth, capture time, and hooked longevity of longline-caught pelagic shark: Timing bites of shaark with chips. Fish Bull 90 (4): 642-658.

Bonfil R, Clarke S, Nakano H. 2008. The biology and ecology of the oceanic whitetip shark, Carcharhinus longimanus. In: Camhi M, Pikitch E, Babcock EA (eds). Sharks of the Open Ocean. Blackwell Publishing, Oxford, UK.

Brothers NP. 1991. Albatross mortality and associated bait loss in the Japanese longline fishery in the SouthernOcean. Biol Conserv 55: 255-268.

Brothers NP, Cooper J, Lokkeborg S. 1999. The Incidental Catch of Seabirds by Longline Fisheries: Worldwide Review and Technical Guidelines for Mitigation. FAO Fisheries Circular No. 937. Food and Agriculture Organization of the United Nations, Rome.

Bromhead D, Clarke S, Hoyle S, Muller B, Sharples P, Harley S. 2012. Identification of factors influencing shark catch and mortality in the Marshall Islands tuna longline fishery and management implications. J Fish Biol 80: 1870-1894.

Camhi M, Fowler S, Musick J, Brautugam A, Fordham S. 1998. Sharks and Their Relatives, Ecology and Conservation. Occasional Paper of the IUCN Spesies Survival Commission No.20. IUCN, Gland, Switzerland and Cambridge, UK.

Clarke S, Sato M, Small C, Sullivan B, Inoue Y, Ochi D. 2014. Bycatch in Longline Fisheries for Tuna and Tuna-Like Species: A Global Review of Status and Mitigation Measures. FAO Fisheries and Aquaculture Technical Paper No. 588. Food and Agriculture Organization of the United Nations, Rome.

Cooper J, Croxall JP, Rivera KS. 2001. Off the hook? Initiatives to reduce seabirds bycatch in longline fisheries. Proceeding of the Symposium-Seabird bycatch: trends, roadblock, and solutions. University of Alaska Sea grant, Alaska.

Cullet P, Patricia A, Mbote K. 1996. Dolphin bycatches in tuna fisheries: a smokescreen hiding the real issues?. Ocean Dev Intl Law 27: 333-348.

De la Serma JM, Valeiras J, Ortiz JM, Macias D. 2002. Large Pelagic Sharks as By-catch in the Mediterranean Swordfish Longline Fishery: Some Biological Aspects. NAFO SCR Doc. 02/137. Serial No. N4759. Northwest Atlantic Fisheries Organisation.

Forney KA, Kobayashi DR. 2007. Updated Estimates of Mortality and Injury of Cetaceans in The Hawaii-Based Longline Fishery 1994-2005. NOAA-TM-NMFS-SWFSC-412.

Garrison LP. 2007. Interactions between marine mammals and pelagic longline fishing gear in the U.S. Atlantic Ocean between 1992-2004. Fish Bull 105: 408-417.

Garrison LP. 2008. Marine mammals. Report of the U.S. Longline Bycatch Reduction Assessment and Planning Workshop. U.S. Dep. Commerce, NOAA Tech. Memo. NMFS-OPR-41.

Gilman E. 2006. Incidental Capture of Seabirds in Pelagic Longline Fisheries of the Tropical and Subtropical Pacific Islands Region and Draft Pacific Islands Regional Plan of Action for Reducing the Incidental Catch of Seabirds in Pelagic Longline Fisheries. Pacific Islands Forum Fisheries Agency, Honiara.

Gilman E, Brothers N, McPherson G, Daizell P. 2006. A review of cetacean interaction with longline gear. Review of cetacean interactions with longline gear. J Cetacean Res Manag 8 (2): 215-223.

Gilman E, Clarke S, Brothers N, Alfaro-Shigueto J, Mandelman J, Mangel J, Petersen S, Piovano S, Thomson N, Dalzell P, Donoso M, Goren M, Werner T. 2007. Shark Depredation and Unwanted Bycatch in Pelagic Longline Fisheries: Industry Practices and Attitudes, and Shark Avoidance Strategies. Western Pacific Regional Fishery Management Council, Honolulu, USA.

Gilman E, Clarke S, Brothers N, Alfaro-Shigueto J, Mandelman J, Mangel J, Petersen S, Piovano S, Thomson N, Dalzell P, Donoso M, Goren M, Werner T. 2008. Shark interactions in pelagic longline fisheries. Mar Policy 32 (1): 1-18.

Godin AC, Carlson JK, Burgener V. 2012. The effect of circle hooks on shark catchability and at⑩vessel mortality rates in longlines fisheries. Bull Mar Sci 88 (3): 469-483.

Hall MA, Alverson DL, Metuzal KI. 2000. By-Catch: Problems and Solutions. Mar Poll Bull 41: 204-219.

IUCN-SSC. 2001. IUCN Red list categories and criteria. IUCN-The World Conservation Union. Gland, Switzerland and Cambridge, UK.

Jimenez S., Domingo A. 2009. Seabird bycatch in the South Atlantic: interaction with uruguayan pelagic longline fishery. Polar Biol 32: 187-196.

Joyce W N. 1999. Management of Sharks Fisheries in Atlantic Canada. Case Studies of the Management Elasmobranch Fisheries. FAO, Rome.

Kettemer LE. 2012. Global Estimate of Shark Mortality Induced by Longline Fisheries. [Hon, Thesis]. Albert-Ludwigs-Universität, Freiburg.

Kizka J, Muir C, Poonian C, Cox TM, Amir OA, Bourjea J, Razafindrakoto Y, Wambitji N, Bristol N. 2009. Marine mammal bycatch in the Soutwest Indian Ocean: Review and need for a Comprehensive status assessment. Western Indian Ocean J Mar Sci 2: 119-136.

Lack M., Sant G. 2006. Confronting Shark Conservation Head On!. TRAFFIC International, Cambridge, UK.

Lewison RL, Crowder LB, Read AJ, Freeman SA. 2004. Understanding impacts of fisheries bycatch on marine megafauna. Trends Ecol Evol 19 (11): 598-604.

Mandelman JW, Cooper PW, Werner TB, Lagueux KM. 2008. Shark bycatch and depredation in the US Atlantic pelagic longline fishery. Rev Fish Biol Fisheries.18: 427-442.

Musyl MK, Brill RW, Curran DS, Fragoso NM, McNaughton LM, Nielsen A, Kikkawa BS, Moyes CD. 2011. Post release survival, vertical and horizontal movements, and thermal habitats of five species of pelagic sharks in the central Pacific Ocean. Fish Bull 109 (4): 341-368.

Nakano H, Matsunaga H, Hiroaki M 2003. Acoustic tracking of bigeye thresher shark, *Alopias superciliosus*, in the eastern Pacific Ocean. Mar Ecol Prog Ser 265: 255-261.

National Aquarium. 2016. Whale. Education Department of National Aquarium. Baltimore, USA.

Nasution C. 1993. Hook rate of kalipo bottom longline in Binuangen Waters, West Java. Jurnal Penelitian Perikanan Laut 81: 40-53. [Indonesian]

Read AJ, Drinker P, Northridge S. 2006.Bycatch of marine mammals in U.S. and global fisheries. Conserv Biol 20: 163-169.

Read AJ. 2007. Do circle hooks reduce the mortality of sea turtles in pelagiclonglines? A review of recent experiments. Biol Conserv. 135: 155-169.

Reeves RR, Berggren P, Crespo EA, Gales N, Nothridge SP, Sciara GND, Read AJ, Rogan E, Smith BD, Warebeek NG. 2005. Global priorities for reducing of cetacean bycatch. WWF, Switzerland.

Rivera K. 2008. NMFS national seabird program: seabird bycatch reduction efforts.Report of the U.S. Longline Bycatch Reduction Assessment and Planning Workshop. U.S. Dep. Commerce, NOAA Tech. Memo. NMFS-OPR-41.

Ryder CE, Conant TA, Schroeder BA. 2006. Report of the Workshop on Marine Turtle Longline Post-interaction Mortality. US Dep Commerce, NOAA Technical Memorandum NMFS-F/OPR-29.

Stehn RA. 2001. Incidental catch of seabirds by longline fisheries in Alaska. Proceeding of the symposium-Seabird bycatch: trends, roadblock, and solutions. University of Alaska Sea Grant, Alaska.

Stobutzki I, Lawrence E, Bensley N, Norris W. 2006. Bycatch Mitigation Approaches in Austalia's Easten Tuna and Billfish Fishery ; Seabirds, Turtles, Marine Mammals, Sharks and Non-Target Fish. Information paper WCPFC-SC2/EBSWG-IP5. The ecosystem and bycatch specialist working group of the second meeting of the scientific committee of the WCPFC, 2006.

Sugiyono. 2006. Statistics for Research. Alfabeta, Bandung. [Indonesian]

Waring G T, Josephson E, Fairfield C P, Foley K M. 2006. U.S. Atlantic and Gulf of Mexico Marine Mammal Stock Assessments—2005. NOAA Tech. Memo. NMFS-NE-194.

Weng KC, Block BA. 2004. Diel vertical migration of the bigeye thresher shark (*Alopias superciliosus*) a species possessing orbital retia mirabilia. Fish Bull 102 (1): 221-229.

WWF. 2004. Working to Reduce Fisheries Bycatch. Factsheet. WWF, Switzerland.

Zainudin IM. 2011. Ecosystem Based Management for Shark Fishery in Indonesia. [Thesis]. FMNS, Universitas Indonesia, Depok. [Indonesian]